DOCUMENT RESUME

ED 204 128 SE 035 223

AUTHOR Hewson, Mariana G.
TITLE Effect of Instruction Using Students' Prior Knowledge and Conceptual Change Strategies on Science Learning. Part I: Development, Application and Evaluation of Instruction.
PUB DATE Apr 81
NOTE 32p.: Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (54th, Grossinger's in the Catskills, Ellenville, NY, April 5-8, 1981). For related document, see SE 035 224.

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Black Students; Cognitive Processes; *Concept Formation; *Concept Teaching; High Schools; High School Students; *Learning Theories; Physical Sciences; *Prior Learning; Science Education; *Science Instruction
IDENTIFIERS Ausubel (David P); *Science Education Research

ABSTRACT

Reported is the development, use, and evaluation of an instructional technique based upon: (1) the assessment of students' prior knowledge; and (2) a theoretical perspective advocated by Ausubel and others which emphasizes the importance of existing knowledge in influencing subsequent concept learning. The experimental group of 46 South African high school students was taught a series of concepts involving mass, volume and density using the special instructional strategy and materials. A control group (N=44) was taught the same concepts using a traditional strategy and materials. Comparison of pretest and posttest scores revealed significantly more knowledge gains for the experimental group. Implications of the results for instruction are discussed. (Author/WB)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED204128

EFFECT OF INSTRUCTION USING STUDENTS' PRIOR KNOWLEDGE AND CONCEPTUAL CHANGE STRATEGIES ON SCIENCE LEARNING PART I: DEVELOPMENT, APPLICATION AND EVALUATION OF INSTRUCTION*

Mariana G. Hewson
Science Education Project, Johannesburg, South Africa

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

M.G. & B. HEWSON

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

*Based on a paper presented at the annual meeting of the National Association for Research in Science Teaching, April 1981.

SE 035 223

ABSTRACT

One of the factors affecting students' learning in science is their existing knowledge prior to instruction. The students' prior knowledge provides an indication of the alternative conceptions as well as the scientific conceptions possessed by the students. This study is concerned primarily with students' alternative conceptions and with instructional strategies to effect the learning of scientific conceptions. i.e. to effect conceptual change from alternative to scientific conceptions. The conceptual change model used here suggests conditions under which alternative conceptions can be replaced by or differentiated into scientific conceptions and new conceptions can be integrated with existing conceptions.

The instructional strategy and materials were developed for a particular student population, namely, black high school students in South Africa, using their previously identified prior knowledge (conceptions and alternative conceptions) and incorporated the principles for conceptual change. The conceptions involved were mass, volume and density.

An experimental group of students was taught these concepts using the special instructional strategy and materials. A control group was taught the same concepts using a traditional strategy and materials. Pre- and post-tests were used to assess the conceptual change that occurred in the experimental and control groups. The results showed a significantly larger improvement in acquisition of scientific conceptions as a result of the instructional strategy and materials which explicitly dealt with student alternative conceptions.

INTRODUCTION

The learning of orthodox science at school is generally regarded as being difficult by students. This is particularly true in South Africa where science examination results of black high school students indicate a disastrous lack of success [see footnote below]. If teaching is a rational enterprise, it should be possible to devise instructional strategies which allow for reliable predictions of instructional outcomes. One of the educational theories having direct implications for instruction is that of David Ausubel (1968) whose well-known maxim states:

> The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly. (p vi)

There is an expanding literature concerning the role of existing knowledge in learning. For example, see Erickson (1980) and Nussbaum (1980) for research reports and Driver and Easley (1978), Nelson (1977), Resnick (1981) and Novak (1977) for research reviews.

This and a subsequent paper report on a study of the role which the knowledge held by students prior to instruction plays in causing student difficulty in learning science. Learning is viewed as a process of conceptual change in which the existing knowledge of individuals is changed in some way. In science teaching, the aim of instruction is that students should acquire scientific knowledge. In other words, the students' existing knowledge changes and develops in the process of incorporating scientific knowledge.

The objectives of the study were:

1. To develop a strategy of instruction based on students' prior knowledge and on the theoretical principles of conceptual change. The content of instruction included the basic scientific concepts of mass, volume, density and relative density.

For example the 1979 Matriculation results for black students in South Africa showed a 4% pass in Physical Science at the Higher Grade level which is the university entrance qualification involving content, basic principles and some application of content. Rote memorization is inadequate for this examination.

2. To apply the strategy of instruction to a specific group of students whose prior knowledge concerning these concepts had been previously identified.
3. To evaluate the effectiveness of the experimental strategy compared with a traditional strategy used as a control.
4. To analyse both experimental and control strategies in terms of the conceptual change model developed by P.W. Hewson (1980) and Posner, et al. (in press) in order to account for the differences obtained.

The study is presented in two parts. This paper deals with the first three objectives, and the second paper with the last of these objectives.

PRIOR KNOWLEDGE

The knowledge that a learner brings to a particular learning situation is called the prior knowledge. Knowledge is described in terms of the hypothetical construct of conceptual frameworks or structures which are described in this study as conceptions.

The word 'conception' is designated to mean both units of information or concepts which are linked together providing coherence or meaning as well as procedural information or intellectual skills concerning the appropriate use of the concepts. Procedural information may be described as plans of action such as those involved in problem solving, classifying biological specimens or doing quadratic equations. A conception is thus seen as an 'organized knowledge unit' (see Hinsley et al. (1977). It is similar to the notions of 'scripts' (Schank and Abelson 1977) 'frames' (Minsky 1977), 'schema' (Rumelhart and Ortony 1977) and 'large scale functional units' (Larkin 1979).

The prior knowledge of a learner is thus seen as a collection of related conceptions. In terms of the instruction rationale which in this study is to teach orthodox science conceptions to students, the

conceptions that are likely to be found in a learner's prior knowledge are the existing scientific conceptions (i.e. the generally accepted scientific concepts which may have been previously learned by the learner), the preconceptions (i.e. the crude undifferentiated notions that have been previously gathered by the learner during life experiences and classroom experiences) and the misconceptions (i.e. the fairly well differentiated conceptions which have become established in the learner's conceptual framework as a result of life experiences, but which differ from the generally accepted scientific conceptions. In this study, the terms misconception and preconception are considered together as alternative conceptions.

Alternative conceptions are thus conceptions formed by individuals intuitively or spontaneously as a result of their everyday experience. They are viable in some limited way in explaining or predicting phenomena. There may, however, be considerable discrepancy between alternative conceptions and scientific conceptions, and from the scientist's point of view, are seen as different or competing conceptions.

There is increasing evidence of the existence of alternative frameworks in children, especially those appropriate to the understanding of natural phenomena. Examples include studies concerning children's conceptions of heat (Erickson 1980, Tiberghien 1980), the particulate nature of matter (Novick and Nussbaum 1978), the earth as a cosmic body (Nussbaum 1979), velocity (Trowbridge and McDermott 1980), mechanics (Driver, personal communication), dynamics (Viennot 1979), and a wide range of concepts in general science (Gilbert and Osborne 1980).

Prior knowledge of mass, volume and density

The prior knowledge concerning mass, volume and density was elicited from a sample of 40 Form 3 (U.S. Grade 10 equivalent) students by means of clinical interviews on a floating and sinking task, and validated by means of a paper and pencil test in a similar but larger sample of 100

Form 3 students (Hewson in preparation). The identified prior knowledge revealed the existence of a variety of scientific and alternative conceptions concerning the basic scientific concepts of mass, volume and density. The alternative conceptions appear to have persisted in Form 2 and 3 students despite the fact that all the students tested had attended classes in which the scientific concepts had been taught at least twice (i.e. once in the primary school, and once in Form 1). Table 1 shows a summary of the alternative conceptions which are the concern of this study. The terms mass and weight are used indiscriminately by students as the conceptual difference between them had not been established. For many of these students the more undifferentiated concept of heaviness is closer to their understanding of mass/weight.

DESIGN

The research involved the development of experimental and control materials used with two similar student groups, the experimental and control groups. A test designed to assess whether students possessed scientific or alternative concepts for mass, volume and density served as both pre- and post-test. The alternative concepts were those previously identified in an equivalent group of students, (Hewson in preparation).

Subjects

Ninety Form II students (Grade 9 equivalent in USA) including both girls and boys with ages ranging from 13 to 20 years were selected from two different neighboring schools, The control group had 44 students and experimental group had 46 students. Both schools were in Soweto, a semi-urban black township near to Johannesburg. The students were of mixed abilities and from various ethnic groups. The conceptual similarity of students in the two groups was established by means of a pre-test.

Test on mass, volume and density

A paper and pencil test was designed to identify the existence of scientific conceptions and alternate conceptions in the students' knowledge.

The test assessed the extent to which the students identified with given statements which were typical of student alternative conceptions (as

identified in the original transcripts of student interviews on the floating and sinking task) or with the orthodox scientific conceptions. The test served as the pre-test in which the conceptual similarity of the two student groups was checked. The same test was also used as the post-test by which the effect of two instructional strategies could be compared.

Structure and analysis of test

The test required the students to indicate whether given statements were correct, incorrect or if they did not understand the statement. In addition the students were asked to amplify on their responses in the space provided after each statement. This provided for a "yes ... but" answer from the students, and provided the tester with a richer understanding of the student response.

The test consisted of 30 items the responses on which were categorised into the following 6 categories:

Scientific conceptions of mass, volume and density

Alternative conceptions of mass, volume and density

An example of a test item follows:

The wood floats because it has no mass. Correct/incorrect/don't understand.

Reason: .....

This item was scored as follows:

If the student indicated 'correct', he or she scored one point in the 'alternative conception of mass' category, because the conception that some objects have no mass is one of the aspects of this alternative conception. If the student indicated 'incorrect' or 'don't understand' no score was given.

Thus each category had a range of item responses. For example a student might identify with 4 of the 6 possible 'alternative conception of volume' responses, and would receive a score of 4 for that category. Since the range of items for each category was different (for example

the category 'conception of volume' had 5 items whereas the category 'alternative conception of mass' had 12 items), the scores for each category were grouped into sub-categories of high scores, medium scores and low scores. This was done by dividing the total number of items for each category into three approximately equal groups (including the score of 0). The student scores (using the sub-categories) for each of the categories of conceptions and alternative conceptions were compared (using a Chi square and significance test) for both the pre- and post-test.

INSTRUCTIONAL STRATEGIES

In general the aim of instruction in this study was to teach the scientific concepts of mass, volume and density to high school students. In other words the instruction was aimed at causing an increase in the number of students who could be said to possess scientific conceptions.

In the experimental instruction it was explicitly stated that the aim was also to cause a decrease in the number of students who possessed alternative conceptions using specific strategies to do this. In the control instruction, however, this was only an implicit aim. In other words, in the control instructional strategy it was hoped that the students would implicitly reject any alternative conceptions they might have as a consequence of instruction.

Control strategy

The formal nature of any orthodox scientific discipline is its logical coherence and axiomatic character which is often considered to be its essential characteristic. While this is a useful model for representing knowledge for a variety of purposes, it has also been traditionally thought of as sufficient for a pedagogical model (di Sessa 1979). Thus the traditional strategy of instruction in science as exemplified in the traditional teaching materials (textbooks and workbooks) can be described as the logical development of ideas which may be treated inductively or

deductively. This logical development involves the intended integration of one conception with the next in a way which is sensible to the teacher. Thus the teaching strategy is described as a series of teaching moves (such as expositions, discussions, experiments or demonstrations) which are designed to integrate new conceptions with existing conceptions and which are set in an axiomatic and logical format.

It is of interest to note that analysis of the more contemporary 'guided discovery' methods of science instruction (such as that implicit in the control materials used in this research) reveal a basic axiomatic and logical format. This is because the materials follow the textbook which follows the syllabus and closely reflects the examination requirements.

Experimental strategy of instruction

Conceptual bridges

According to Novak (1977), if students are helped to establish relevant mental sets at the beginning of instruction, there is a significant improvement in the way in which information is learned i.e. "internalized in cognitive structure" (p 82). Relevant mental sets are established by making use of general, more inclusive concepts which are both familiar to the students and appropriate to the subject matter being taught. Such concepts serve to bring to mind a network of associated concepts.

This network constitutes the mental set which provides the context for the instructional sequence. It also serves as the conceptual bridge between the students' knowledge prior to instruction and the knowledge contained in the instructional sequence.

The concepts used for these purposes in this study were embedded in the familiar experience that some things sink and others float when put in water. This phenomenon was demonstrated to the students at the beginning of the instructional sequence, and the question posed was "Why do things float or sink in water?" From previous research (Hewson, in preparation)

the range of student responses to this question was known, and the alternative conceptions had been identified. The units of instruction were thus organized around the following selected alternative conceptions i.e. "It is the mass/weight" (unit 1),

"It is the size (volume)" (unit 2),

"It is the material", "it is the particles" (unit 3),

"It is the 'density' i.e. denseness of particles" (unit 4).

Each unit began with the bridge question, and immediately thereafter dealt with the alternative conceptions. The method by which the instructional strategies dealt with the prior knowledge of the students is discussed in the context of conceptual change.

Conceptual change

The conceptual change model developed by P.W. Hewson (1980) and Posner et al (in press) outlines the processes by which existing conceptual frameworks change and develop. While Ausubel's theory deals with the method by which new concepts become incorporated with existing concepts and existing concepts become differentiated (assimilation theory) it does not consider how certain concepts, particularly alternative concepts may be exchanged for others. The conceptual change model does do this, and in addition provides a suggested mechanism by which conceptual change takes place. The conceptual change model and its application to this study are discussed in a subsequent paper.

Teaching Moves

The teaching moves implicit in the model were designed to have the following intended outcomes:

1. Integration of new conceptions with existing conceptions or of conceptions with each other

This could involve instantiation, extrapolation, elaboration of existing conceptions, or subsumption whereby a new conception is integrated with existing conceptions by means of bridge concepts. For

example the existing conception of 'packing of particles' concerned only the effect of packing on the number of particles and consequently on the mass of the object. The conception that particles of a particular material have a particular mass and that different materials have particles with different masses was new for these students. It was introduced and integrated with existing concepts by means of concrete models of particles of iron, glass and wood.

2. Exchange of alternative conceptions

Existing alternative conceptions are exchanged in favour of scientific conceptions through teaching moves designed to cause conceptual conflict. Contradictory, rival conceptions are presented to the learners and the situation is designed so that the learner is able to see the new conception as having more explanatory and predictive power than the existing alternative conception. For example, the scientific concept of density (the mass per unit volume of a substance) is more powerful than the alternative conception of 'denseness of particles' (the way the particles are packed). One of the reasons for this is that scientific density is measurable and thereby provides predictive and explanatory power concerning the behavior of objects in water. Thus while the alternative conception of 'denseness of particles' is apparently sensible to the students, it has no predictive power and can only be used as a tautology, i.e. an object sinks, therefore its particles are closely packed and that is why it sinks.

3. Differentiation of alternative conceptions.

Some of the alternative conceptions are ill defined or "fuzzy" conceptions e.g. "mass/weight is heaviness" and others are confused conceptions e.g. "density = denseness". The differentiation of such concepts requires the redefinition of fuzzy conceptions (e.g. mass is a measure of the amount of matter in an object which is experienced

as heaviness",) and the separation of confused conceptions (e.g. dense means the number of objects in a given area but density means the mass of objects for a particular volume). The differentiation of alternative conceptions may be effected directly by specially designed teaching moves or indirectly as a consequence of other conceptual changes (integration or exchange).

Each of these teaching moves required active participation by the learners. This took the form of discussions, workbook activities, demonstrations or experiments.

INSTRUCTIONAL MATERIALS

The experimental and control materials consisted of four units of instruction concerning mass, volume, the particulate nature of matter and density with relative density. Each unit took approximately 1 hour of class time.

Both the experimental and control materials contained identical core materials taken from the Science Education Project (SEP) Physical Science worksheets for Form I. The SEP materials include worksheets, teacher's guide and apparatus kit. They form an innovative approach to the teaching of science by active student involvement. Evaluation of these materials has shown significant improvement in student examination results compared with those from non-SEP schools. (Rogan 1980).

Control Materials

The core materials were used in conjunction with the prescribed textbook: New Structure General Science Form I (Pahl, Fourie & Makunga 1975). The teaching sequence followed the textbook which involves the following topics: measurement, volume, mass, density, relative density and the particulate nature of matter. Each unit involved student participation in experiments and answering questions. In these materials no provision was made for student alternative conceptions.

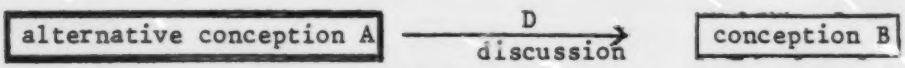
Experimental Materials

The core materials were embedded within specially prepared teaching materials using the same worksheet format which incorporated the teaching moves of the experimental instructional strategy discussed earlier.

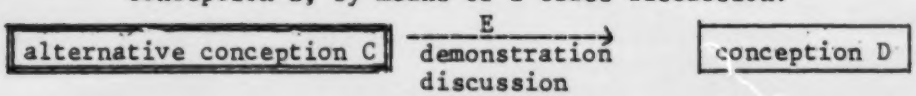
A summary of the control and experimental instructional units is given in Figures 1, 2, 3 and 4. Each figure shows the experimental instructional strategy (lower case) superimposed upon the control instructional strategy (upper case). The control units of instruction thus provided the core material for the experimental units of instruction. The difference between the control and experimental instructional units is thus clearly seen to be the focus given to the students' alternative conceptions.

Representation of the materials

Figures 1, 2, 3 and 4 are schematic representations of the conceptions and alternative conceptions involved in the instructional sequence. The 'teaching moves' are depicted as the connections (arrows) between the conceptions. The direction of the arrows indicates the approximate order of presentation of the ideas. The intended outcomes of the teaching moves are written as the conceptual changes: differentiation (D); integration (I) and exchange (E). The conceptions and alternative conceptions are depicted differently as shown in the examples below:



Read: The alternative conception A was differentiated into the conception B, by means of a class discussion.



Read: The alternative conception C was exchanged in favor of conception D, by means of a demonstration and discussion.

conception E $\xrightarrow[\text{experiment}]{\text{I}}$ conception F

Read: The conception F was integrated with conception E by means of an experiment.

RESULTS

The results of the pre-and post-test analyses are given in Tables 2 and 3. The tables show the number of students in the control (C) and experimental (E) groups who were categorized as having high, medium or low scores for each conception, or alternative conception (see earlier section on test analysis).

The pre-test comparison between experimental and control groups showed no significant differences between the groups for all the categories (see Table 2). This provides the validation that the two groups were essentially similar with respect to their conceptions and alternative conceptions prior to instruction. The post-test comparison between experimental and control groups showed significant differences, all at the .01 level as seen in Table 3. These results indicate that the experimental instructional strategy resulted in learning of scientific concepts that was significantly different from the control instructional strategy. The nature of this difference can be seen in Table 4 in which the scores of each category were converted into an arbitrary index of student performance (the index score). The changes in index scores from the pre-to post-test were calculated as change index scores and given as percentages of the number of students in each group i.e.

$$\text{change index} = \frac{\text{post index score} - \text{pre index score}}{N} \times 100\%.$$

Figure 5 represents these change index scores for the control and experimental groups for each of the 6 categories. It can clearly be seen that the experimental group achieved higher positive change index scores for each of the scientific conceptions than the control group. Conversely, the experimental group achieved higher negative change index scores for the alternative conceptions of mass and volume than the control group.

Both groups achieved approximately the same negative change index score for the alternative conception of density.

Discussion

The fact that the control group showed poor progress in the acquisition of scientific conceptions of mass, volume and density should not be surprising. They had, as mentioned earlier, been exposed to traditional instruction on these concepts at least twice before without having acquired them. Thus the control instructional sequence used in this research was apparently as ineffective as the previous ones, while the experimental group showed considerable improvement.

The results indicate that the experimental and control groups showed approximately the same decrease in the presence of the alternative conception of density, and the decrease was not very great (change index scores of -23.9% and -25.0% for experimental and control groups respectively). This is interpreted as evidence of the "tenacity" and "resistance to extinction" of alternative conceptions, as discussed by Ausubel (1968). The more established alternative conceptions are more difficult to eliminate. In terms of the conceptual change model, this is because the individual possessing the alternative conceptions finds them useful to a limited extent. The instructional strategy therefore has to be designed in such a way that the individual is convinced that the scientific conception is more useful. This is not a simple endeavour!

It is clear that the control group retained their alternative conceptions of mass and volume and to a lesser extent of density. Apparently their understanding of the scientific conception of mass lessened, and it can be assumed that the students became more confused than they were prior to instruction. Also, their acquisition of the scientific conceptions of density and volume were considerably lower than for the experimental group. It would appear that the cause of the poor progress of the control students in acquiring scientific conceptions lies with the

continued presence of the alternative conceptions in their conceptual frameworks. It also appears that the reason the experimental students were able to acquire the scientific conceptions was that the alternative conceptions had been reduced even if not completely eliminated in the course of instruction.

Although the results indicate a significantly greater acquisition of scientific conceptions in the experimental group than in the control group, it must be pointed out that the experimental students still did not have a good understanding of the scientific concepts after instruction. There is therefore room for improvement in effecting conceptual change from existing alternative conceptions to scientific conceptions. Nevertheless, the conceptual change strategy used in this research holds much promise for improving science education, and deserves further research.

SUMMARY AND IMPLICATIONS

The scientific conceptions of mass, volume and density were taught to two groups of students using two different instructional strategies. The experimental instructional strategy was designed to lead students from their existing knowledge (which included alternative conceptions) to the scientific knowledge. The traditional instructional strategy followed the logical presentation of concepts usually seen in textbooks on introductory physical science.

The experimental instructional strategy caused a significantly better acquisition of scientific conceptions and elimination of alternative conceptions than the control strategy. The difference between the two strategies was that the experimental strategy explicitly dealt with student alternative conceptions while the control strategy did not. The method of dealing with these alternative conceptions was to use strategies of conceptual change designed to promote the acquisition of certain conceptions as a consequence of the exchange and differentiation of the existing conceptions, and the integration of new conceptions with

existing conceptions. These results demonstrate the importance of using instructional strategies in science which address student alternative conceptions rather than traditional instructional strategies which are derived from the formal view of science as being axiomatic and logical in character.

This research has focussed on the importance of alternative conceptions in a particular student group, namely black high school students in Soweto, South Africa. Nevertheless, the research has implications for science education in general as well as for science education in multi-cultural societies. If prior knowledge in individuals exists as a consequence of both their experience of worldly facts and events and their cultural and personal beliefs and theories (see Petrie 1976) then different groups will be likely to have different prior knowledge involving different alternative conceptions. Thus while it is likely that inter-cultural differences exist, it is also likely that intra-cultural differences exist, and that students within the same cultural group have a wide range of conceptions and alternative concepts in their prior knowledge. Evidence to support this is currently being provided by the researchers mentioned earlier.

The need for educators to be aware of and deal with student alternative conceptions is great. The difficulty lies in discovering what these alternative concepts are especially as a researcher may have no preliminary knowledge about what to look for when testing students. The research papers quoted above provide methods for doing this. Once educators are aware of the existence of alternative conceptions, they can be recognized in students' prior knowledge and subsequently dealt with in the course of instruction. Extensive and intensive research into the elements of student prior knowledge is required. Without this information the likelihood

is that educationalists will continue to use traditional methods, unaware of the importance of alternative conceptions. In traditional instruction the alternative conceptions may be counter productive. They may however be seen as the keys to successful teaching if explicitly dealt with in the course of instruction. Both roles of alternative conceptions have been demonstrated in this research.

FIGURE CAPTIONS

Figure 1: Representation of teaching moves and scientific and alternative conceptions involved in the experimental and control instruction on the topic of MASS

Figure 2: Representation of teaching moves and scientific and alternative conceptions involved in the experimental and control instruction on the topic of VOLUME

Figure 3: Representation of teaching moves and scientific and alternative conceptions involved in the experimental and control instruction on the topic of the PARTICULATE NATURE OF MATTER

Figure 4: Representation of teaching moves and scientific and alternative conceptions involved in the experimental and control instruction on the topic of DENSITY and RELATIVE DENSITY

Figure 5: Comparison of the conceptual change index scores for the experimental and control groups, for the scientific and alternative conceptions of mass, volume and density

TABLE CAPTIONS

Table 1 A comparison of the scientific conceptions with the alternative conceptions of mass, volume and density as identified in a group of black high school students in South Africa.

Table 2 Pre-test scores for control (C) and experimental (E) groups. All categories show no significant differences between the two groups prior to instruction.

Table 3 Post-test scores for control (C) and experimental (E) groups. All categories show significant differences between the two groups following instruction.

Table 4 Summary of scores for the control and experimental groups in which the scores on each category are given arbitrary values of low = -1, medium = 0, high = +1. The sum of scores provides an index of student performance on each category. The change index is the difference between the pre-test index score and the post-test index score given as a percentage of the number of students in each group.

REFERENCES

Ausubel, D.P. Educational psychology: a cognitive view. New York: Holt, Rinehart and Winston Inc., 1968.

di Sessa, A. On learnable representations of knowledge: a meaning of the computational metaphor. In J. Lochhead and J. Clement (Eds.) Cognitive process instruction. Philadelphia: Franklin Institute Press, 1979.

Driver, R., and Easley, J.A. Pupils and paradigms: a review of literature related to concept development in adolescent science students. Studies in Science Education, 1978, 5, 61-84.

Erickson, G. Childrens' viewpoints of heat. Science Education, 1980, 64, 323-338.

Gilbert, J.K., and Osborne, R.J. Identifying science students' concepts: The interview-about-instances approach. In W.F. Archenhold et al (Eds.) Cognitive development research in science and mathematics. Leeds: Univ. of Leeds Printing Service, 1980.

Hewson, P.W. A case study of the effect of metaphysical commitments on the learning of a complex scientific theory. Paper presented at the annual meeting of AERA, Boston, 1980. ERIC: ED 189 178.

Hinsley, D., Hayes, J.R., and Simon, H.A. From words to equations. In P. Carpenter and M. Just (Eds.) Cognitive processes in comprehension. Hillsdale, N.J. : Lawrence Erlbaum Associates, 1977.

Larkin, J.H. Information processing models in science instruction. In J. Lochhead and J. Clement (Eds.) Cognitive process instruction. Philadelphia: Franklin Institute Press, 1979.

Minsky, M. Frame-system thinking. In P.N. Johnson-Laird and P.C. Wason (Eds.) Thinking. Cambridge: Cambridge University Press, 1977.

Nelson, K. Cognitive development and the acquisition of concepts. In R.C. Anderson, R.J. Spiro and W.E. Montague (Eds.) Schooling and the acquisition of knowledge. Hillsdale N.J. : Lawrence Erlbaum Associates, 1977.

Novak, J.D. A theory of education. Ithaca: Cornell University Press, 1977.

Novick, S. and Nussbaum, J. Junior high school pupils' understanding of the particulate nature of matter: An interview study. Science Education, 1978, 62, 273-281.

Nussbaum, J. Childrens' conceptions of the earth as a cosmic body : a cross age study. Science Education, 1979, 63, 83-93.

Nussbaum, J. Towards the diagnosis by science teachers of pupils' misconceptions: an exercise with student teachers. In W.F. Archenhold et al (Eds.) Cognitive development research in science and mathematics. Leeds: University of Leeds Printing Service, 1980.

Pahl, H.W., Fourie, D.I., and Makunga, O.H.D. New structure general science: Form I. Elsies River, S.A. : Via Africa Ltd., 1975.

Petrie, H.G. Evolutionary rationality: or can learning theory survive the jungle of conceptual change? Philosophy of Education, 1976, 117-132.

Posner, G.J., Strike, K.A., Hewson, P.W. and Gertzog, W.A. Accommodation of a scientific conception: toward a theory of conceptual change. Science Education, In press.

Resnick, L.B. Instructional psychology. Annual Review of Psychology. 1981, 32.

Rogan, J.M. The Std 6 and Std 7 general science examination results for 1979 in the Alice and Middledrift circuits. Science Education Project Report, University of the Witwatersrand, Johannesburg, 1980.

Rumelhart, D.E., and Ortony, A. The representation of knowledge in memory. In R.C. Anderson, R.J. Spiro and W.E. Montague (Eds.) Schooling and the acquisition of knowledge. Hillsdale, N.J. : Lawrence Erlbaum Associates, 1977.

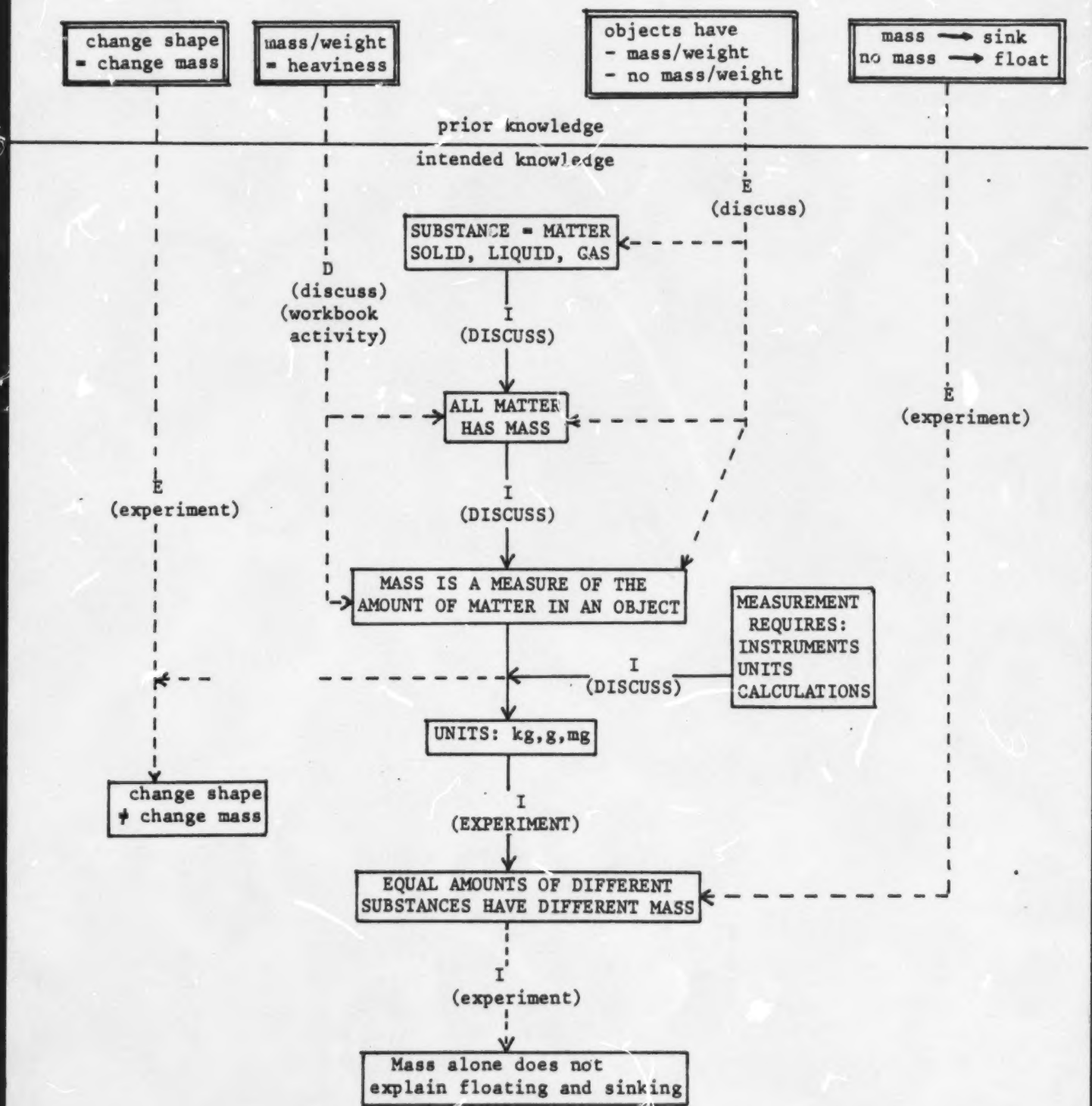
Schank, R.C., and Abelson, R.P. Scripts, plans and knowledge. In P.N. Johnson-Laird and P.C. Wason (Eds.) Thinking. Cambridge: Cambridge University Press, 1977.

Tiberghien, A. Modes and conditions of learning - an example : the learning of some aspects of the concept of heat. In W.F. Archenhold et al (Eds.) Cognitive development research in science and mathematics. Leeds : University of Leeds Printing Service, 1980.

Trowbridge, D.E. and McDermott, L.C. An investigation of student understanding of the concept of velocity in one dimension. American Journal of Physics, 1980, 48, 1020-1028.

Viennot, L. Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1979, 1, 205-221.

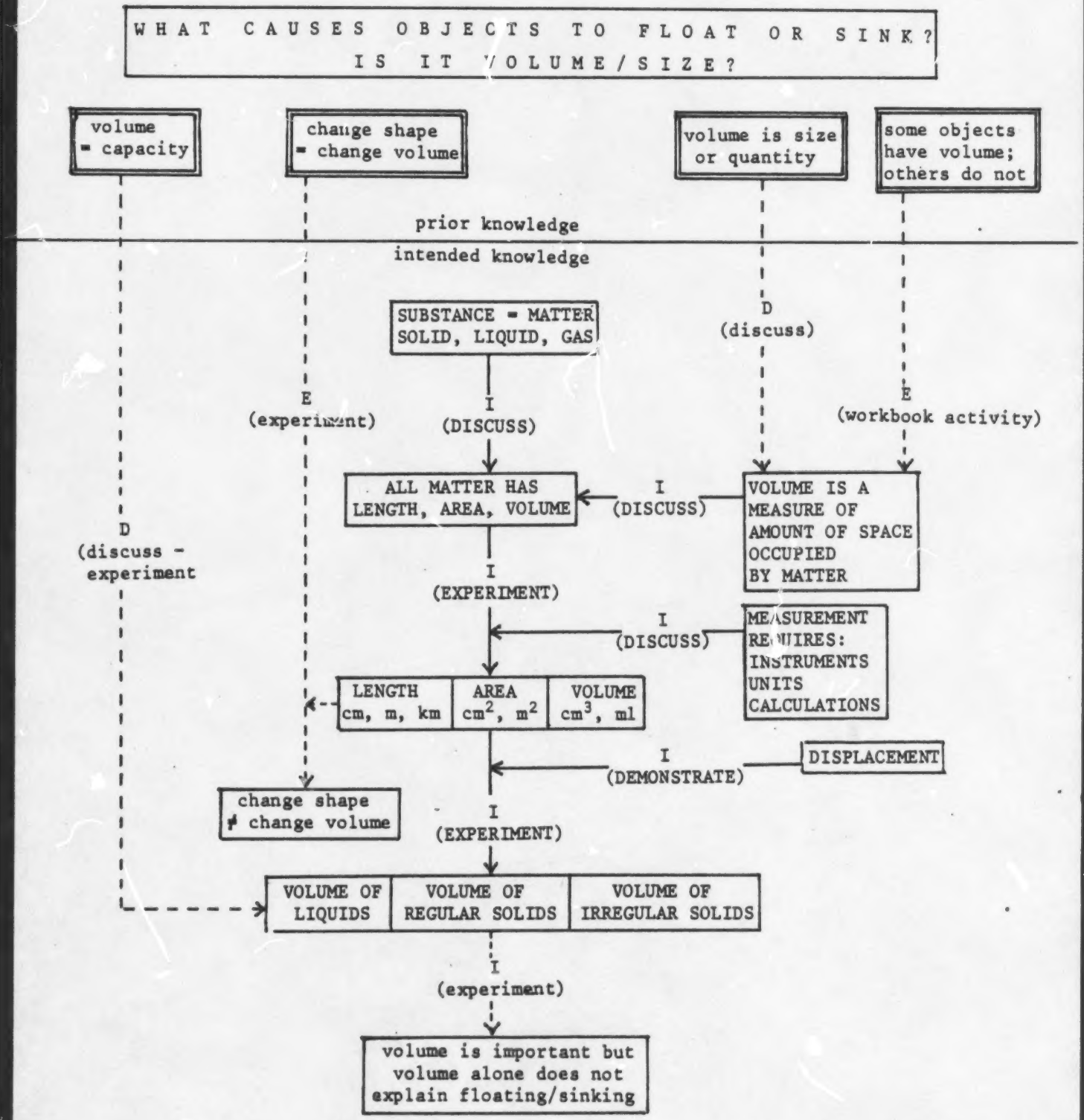
WHAT CAUSES OBJECTS TO FLOAT OR SINK?
IS IT MASS/WEIGHT?


change shape = change mass
mass/weight = heaviness
objects have - mass/weight - no mass/weight
mass → sink
no mass → float
prior knowledge
intended knowledge
E (discuss)
SUBSTANCE = MATTER SOLID, LIQUID, GAS
D (discuss) (workbook activity)
I (DISCUSS)
ALL MATTER HAS MASS
E (experiment)
I (DISCUSS)
MASS IS A MEASURE OF THE AMOUNT OF MATTER IN AN OBJECT
MEASUREMENT REQUIRES: INSTRUMENTS UNITS CALCULATIONS
I (DISCUSS)
UNITS: kg,g,mg
change shape ≠ change mass
I (EXPERIMENT)
EQUAL AMOUNTS OF DIFFERENT SUBSTANCES HAVE DIFFERENT MASS
I (experiment)
Mass alone does not explain floating and sinking

UPPER CASE: Experimental and control instruction
lower case: Experimental instruction only

I = integration E = exchange
D = differentiation

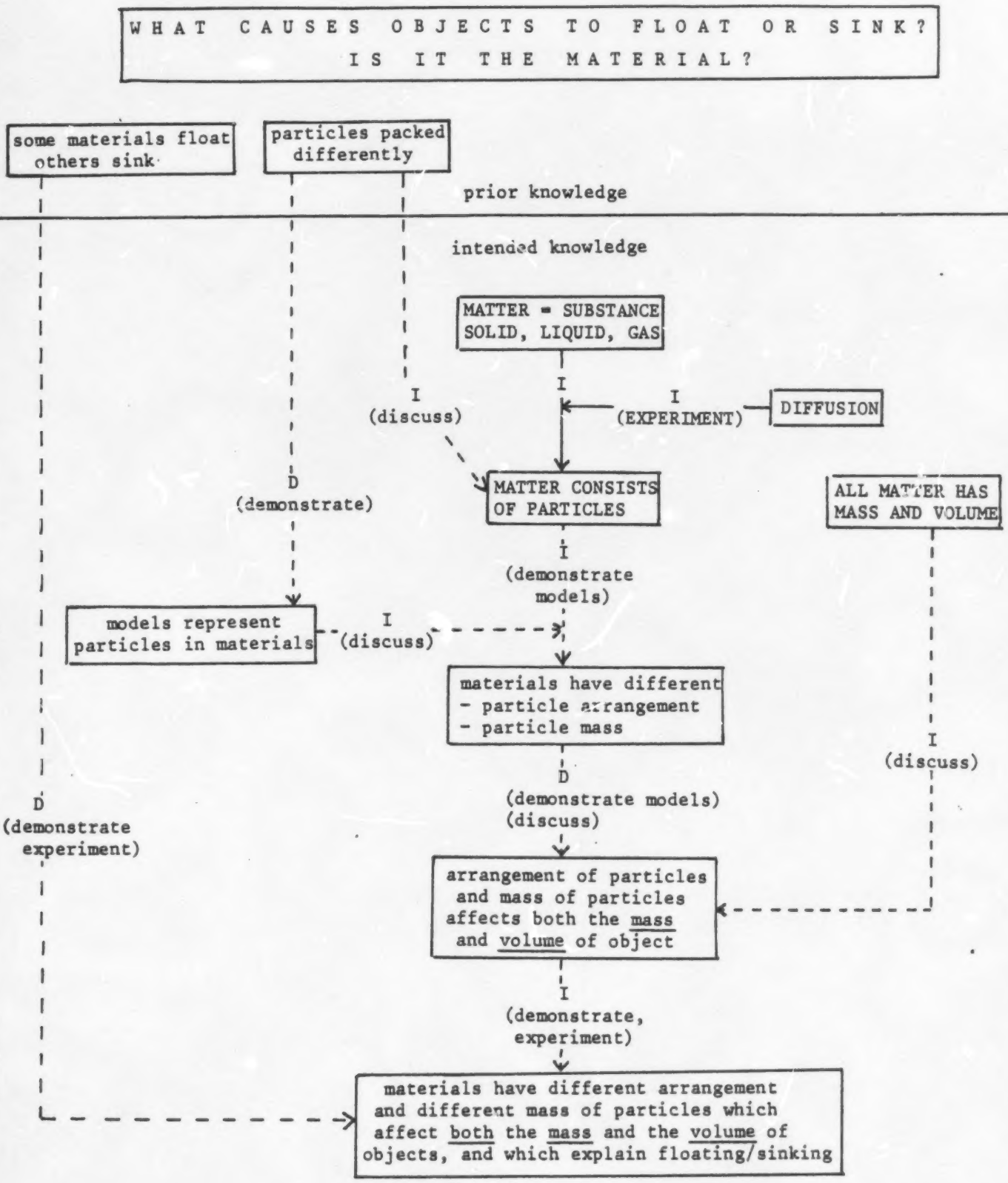
Identified prior knowledge lies above the line



I = integration E = exchange
D = differentiation

Identified prior knowledge lies above the line

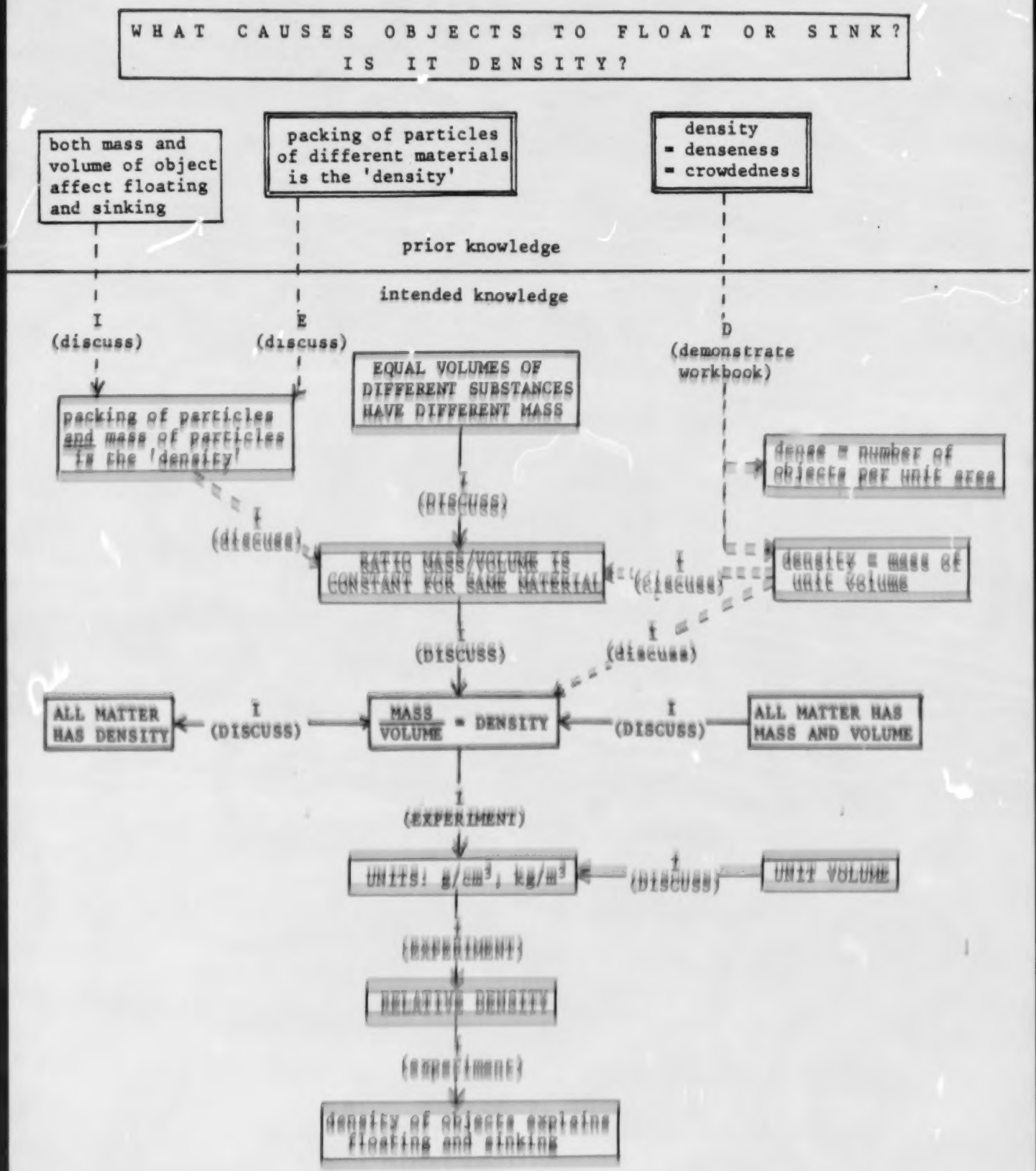
UPPER CASE: Experimental and control instruction
lower case: Experimental instruction only


WHAT CAUSES OBJECTS TO FLOAT OR SINK?
IS IT THE MATERIAL?
some materials float others sink
particles packed differently
prior knowledge
intended knowledge
MATTER = SUBSTANCE SOLID, LIQUID, GAS
I (discuss)
I (EXPERIMENT)
DIFFUSION
D (demonstrate)
MATTER CONSISTS OF PARTICLES
ALL MATTER HAS MASS AND VOLUME
I (demonstrate models)
models represent particles in materials
I (discuss)
materials have different
- particle arrangement
- particle mass
I (discuss)
D (demonstrate models) (discuss)
D (demonstrate experiment)
arrangement of particles and mass of particles affects both the mass and volume of object
I (demonstrate, experiment)
materials have different arrangement and different mass of particles which affect both the mass and the volume of objects, and which explain floating/sinking

UPPER CASE: Experimental and control instruction
lower case: Experimental instruction only

Identified prior knowledge lies above the line

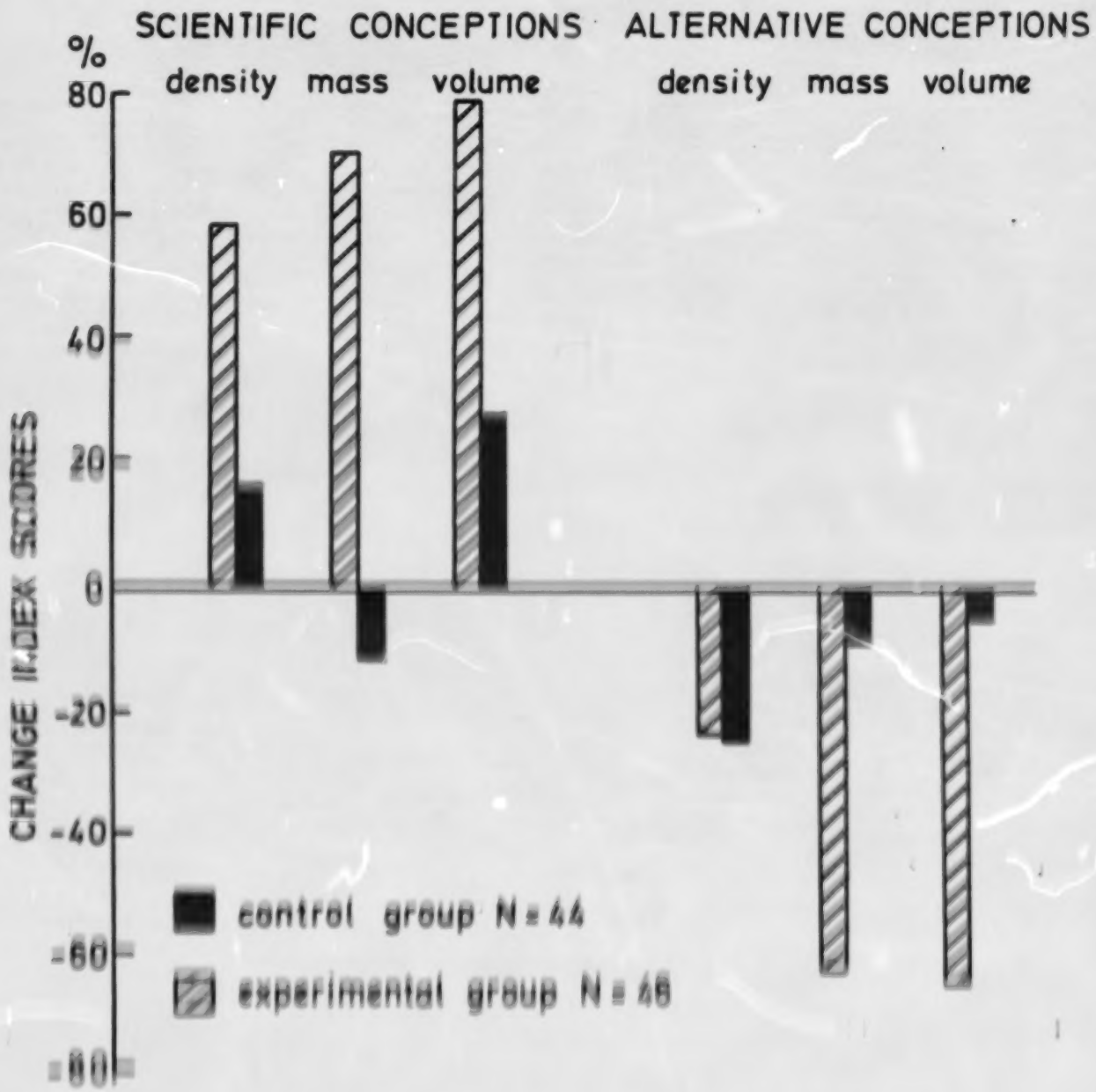
I = integration E = exchange
D = differentiation


WHAT CAUSES OBJECTS TO FLOAT OR SINK?
IS IT DENSITY?
both mass and volume of object affect floating and sinking
packing of particles of different materials is the 'density'
density = denseness = crowdedness
prior knowledge
intended knowledge
I (discuss)
E (discuss)
D (demonstrate workbook)
packing of particles and mass of particles is the 'density'
EQUAL VOLUMES OF DIFFERENT SUBSTANCES HAVE DIFFERENT MASS
dense = number of objects per unit area
I (discuss)
I (DISCUSS)
RATIO MASS/VOLUME IS CONSTANT FOR SAME MATERIAL
I (discuss)
density = mass of unit volume
I (DISCUSS)
I (discuss)
ALL MATTER HAS DENSITY
I (DISCUSS)
MASS / VOLUME = DENSITY
I (DISCUSS)
ALL MATTER HAS MASS AND VOLUME
I (EXPERIMENT)
UNITS: g/cm³, kg/m³
I (DISCUSS)
UNIT VOLUME
(EXPERIMENT)
RELATIVE DENSITY
(experiment)
density of objects explains floating and sinking

I = integration E = exchange
D = differentiation

Identified prior knowledge lies above the line

UPPER CASE: Experimental and control instruction
lower case: Experimental instruction only


SCIENTIFIC CONCEPTIONS
ALTERNATIVE CONCEPTIONS
%
density mass volume
density mass volume
80
60
40
20
0
-20
-40
-60
-80
CHANGE INDEX SCORES
control group N = 44
experimental group N = 46

	Scientific conceptions	Alternative conceptions identified in student group
mass/weight	mass is a measure of the amount of matter in an object all matter has mass units of measurement are grams, kilograms	mass/weight = heaviness some objects have mass/weight (brick, stone), while others do not (feather, pin, hair) change shape = change mass mass/weight = density
volume	volume is the amount of space occupied by matter all matter has volume units of measurement are millilitres or cubic centimetres	volume = size or quantity volume = capacity some objects have volume (water in cup, flour in bag), while others do not (cup, bag, pin) change shape = change volume
density	density is the ratio of the mass per unit volume of a substance units of measurement are grams per cubic centimetre	density = mass/weight density = denseness = crowdedness density = packing of particles i.e. closely packed = dense loosely packed = not dense density depends on material of object, i.e. way in which particles are packed

concept	group	scores			X^2	degrees of freedom
		low	medium	high		
density	C	40	4	0	1,0	1
	E	42	4	0		
alternative density	C	7	36	1	2,0	2
	E	13	32	1		
mass	C	17	27	0	1,1	2
	E	19	26	1		
alternative mass	C	4	35	5	2,9	2
	E	2	33	11		
volume	C	27	17	0	2,2	1
	E	20	26	0		
alternative volume	C	4	24	16	0,4	2
	E	4	28	14		

(C) group N = 44

(E) group N = 44

concept	group	scores			X^2	degrees of freedom
		low	medium	high		
density	C	34	9	1	15,0**	2
	E	17	27	2		
alternative density	C	17	27	0	9,7**	2
	E	27	15	4		
mass	C	24	18	2	25,0**	2
	E	7	18	21		
alternative mass	C	9	29	6	11,3**	2
	E	25	16	5		
volume	C	17	25	2	23,0**	2
	E	6	18	22		
alternative volume	C	4	26	14	21,3**	2
	E	24	18	4		

(C) group N = 44

(E) group N = 46

* $p < .05$

** $p < .01$

concept	group	index score for pre-test	index score for post-test	amount of change in index scores	change index %
density	C	-40	-33	+7	+15,9
	E	-42	-15	+27	+58,7
mass	C	-17	-22	-5	11,4
	E	-18	+14	+32	+69,6
volume	C	-27	-15	+12	+27,3
	E	-20	+16	+36	+78,3
alternative density	C	-6	-17	-11	-25,0
	E	-12	-23	-11	-23,9
alternative mass	E	+1	-3	-4	-9,1
	E	+9	-20	-29	-63,0
alternative volume	C	+12	+10	-2	-4,5
	E	+10	-20	-30	-65,2

$$\text{change index} = \frac{\text{post index score} - \text{pre index score}}{N} \times 100\ \%$$

(C) N = 44

(E) N = 46